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INSTRUCTION BOOK
MODEL 75A-S8 (After Ser. # 328)
CAPACITANCE BRIDGE

SERIAL NO. ____

BOONTON ELECTRONICS CORPORATION

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MODEL 75A-S8 (After Ser. # 328)
CAPACITANCE BRIDGE

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The Model 75A-S8 Capacitance Bridge has all of the basic features of the Model 75A, plus provisions for biasing the component under test with DC from internal supplies, or from an external source. Bias may be applied only when making "DIRECT" capacitance measurements. The circuit modifications used normally limit operation to 1 MC (whether or not bias is applied).

A switch selects internal bias of either polarity, no bias, or external bias. The level of the internal bias is continuously adjustable from 0 to +125V or -5 V, using the ADJUST control.

Internal bias voltage and current may be monitored at the VOLTAGE posts and CURRENT jack provided (circuit improvements have eliminated all paths for the bias current except through the test).

Posts are provided to allow up to 400 V at 100 ma. to be applied from an external source, but adjustment and monitoring must then be done at the source.

75A INSTRUCTION BOOK

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SPECIFICATIONS

CAPACITANCE:

200 μpf to 1000 pf in 4 decade ranges

Multi-plier	Capacitance Range	Accuracy *	
1	100-1000 pf (0.2 pf/div.)	± (0.25% + $\frac{1000}{R_p}$ pf + 0.5 pf) ± (" + " + 1.0 pf)	Direct Grounded
.1	10-100 pf (0.02 pf/div.)	± (" + " + 0.02 pf) ± (" + " + 0.5 pf)	Direct Grounded
.01	1-10 pf (0.002 pf/div.)	± (" + " + 0.005 pf) ± (" + " + 0.5 pf)	Direct Grounded
.001	0.05-1 pf 0-0.05 pf (0.0002 pf/div.)	± (" + " + 0.001 pf) ± (2% + " + 0.0002 pf)	Direct Direct

Where R_p is the equivalent parallel resistance of the test in ohms.

CONDUCTANCE:

0.01 to 1000 micromhos in 4 decade ranges

Divider	Conductance Range	Accuracy*
1	100 to 1000 μmhos	$\pm(10\% + \frac{Q}{500}\% + 10\ \mu\text{mhos})$
10	10 to 100 μmhos	$\pm(10\% + \frac{Q}{500}\% + 1\ \mu\text{mho})$
100	1 to 10 μmhos	$\pm(10\% + \frac{Q}{500}\% + 0.1\ \mu\text{mho})$
1000	0 to 1 μmho	$\pm(10\% + \frac{Q}{500}\% + 0.01\ \mu\text{mho})$

RESISTANCE:

1000 Ω to 100 megohms in 4 decade ranges

Multiplier	Resistance Range	Accuracy*
1	1K to 10K	$\pm(10\% + \frac{Q}{500}\% + \frac{R}{10^3}\%)$
10	10K to 100K	$\pm(10\% + \frac{Q}{500}\% + \frac{R}{10^4}\%)$
100	100K to 1 megohm	$\pm(10\% + \frac{Q}{500}\% + \frac{R}{10^5}\%)$
1000	1 megohm to ∞	$\pm(10\% + \frac{Q}{500} \quad \frac{R}{10^6}\%)$
Where R is the measured resistance in ohms.		

*These specifications apply to tests made directly at the HI and LO TEST binding posts or coaxial receptacles. See Section 5 "Measuring Techniques" for limitations applicable to remote measurements.

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TEST FREQUENCY:

With self contained oscillator and detector 1 Mc ± 10 Kc.
* With external oscillator and detector 100 Kc to 1 Mc.

SIGNAL LEVEL ACROSS TEST:

Adjustable from approximately 20 millivolts to 3 volts.

TUBE COMPLEMENT:

1 each 6C4, 6X4 and 0A2.
3 each 6AU6.

POWER REQUIREMENTS:

105 - 125V, 50 - 60 cps, 30 W.

WEIGHT:

In cabinet 32 lbs.
Rack 25 lbs.

SIZE:

11-1/4H x 19-1/2W x 12-3/4D overall in cabinet.
10-1/2H x 19W x 10-1/8D behind panel when rack mounted.

* Model 75A only

SECTION 2

GENERAL DESCRIPTION

The Model 75A is a sensitive, accurate, stable capacitance bridge, designed primarily to meet the need for precise measurements at one megacycle. Either three-terminal (direct) or two-terminal (grounded) measurements may be made.

As in its 100 KC counterpart the 74D, the 75A features direct reading dials, excellent resolution and sensitivity, a high order of accuracy in measuring very small values of capacitance, and provision for differential measurements. It is completely self-contained; with built-in 1 MC oscillator, 1 MC detector, and integral power supply.

The versatile design also allows it to be used with an external oscillator and detector at any frequency between 100 KC and 1 MC.*

Provision for varying the level of the 1 MC test signal is standard. A modified version of the 75A (designated the (75A-S8) is available that provides a built-in adjustable D.C. bias for measuring the direct-capacitance of voltage variable semi-conductor diodes and other voltage sensitive capacitors.

* Model 75A only

SECTION 3

THREE-TERMINAL (DIRECT) CAPACITANCE VS. GROUNDED CAPACITANCE

Direct-capacitance is the capacitance existing between two conducting elements, excluding all stray capacitance that may exist to other conducting elements.

Typical examples of Direct-capacitance measurements are:

a. Capacitance between the control grid and plate of a pentode vacuum tube, excluding capacitance to cathode, screen grid, or suppressor.

b. Capacitance between any two conductors in a cable, excluding capacitance to all other conductors or the shield.

c. Capacitance between any two conductors of a printed circuit, excluding capacitance to all other conductors

d. Capacitance between any two windings of a transformer, excluding capacitance to all other windings or shields.

Grounded capacitance is the capacitance existing between two conducting elements when one element is grounded, and include all stray capacitance from the high side of the element to ground, either directly or by way of adjacent elements. For this reason, a grounded capacitance reading will always be greater than a direct-capacitance reading and will depend upon the proximity of the chassis, adjacent components, and measuring technique.

SECTION 4

OPERATING PROCEDURE

4.1 SET UP AND ZERO BALANCING

a. Turn the power switch on. Select the desired method of capacitance measurement; set the GND/DIR (grounded/direct) switch accordingly.

b. Set the conductance range selector switch (marked DIVIDE G/MULTIPLY R) to 1,000.

c. Set the MULTIPLY C switch to the position indicated below:

Range of Capacitance To Be Measured	Setting of MULTIPLY C Switch
1000 - 100 pf	1
100 - 10 pf	0.1
10 - 1 pf	0.01
1 - 0 pf	0.001

d. Set the CONDUCTANCE dial to zero.

e. Set the CAPACITANCE dial to zero. (Both vernier and counter dials should read zero).

f. If they are required, connect test leads or fixtures as detailed in Section 5 "Measuring Techniques".

g. If the test signal must be set at a definite level, connect a suitable Ac VTVM to the LO TEST receptacle and use the OSC LEVEL controls to adjust to the desired value. (The normal range of adjustment is approximately 3 v maximum to 20 Mv minimum. If lower levels are needed, a 75-1A 40 db pad should be installed on J1. This provides an adjustment range between about

40 Mv and 0.5 Mv). Leave the VTVM connected for step (h) that follows.

h. Adjust zero balance controls (located to the right of the main CAPACITANCE and CONDUCTANCE dials) until the NULL INDICATOR meter reads nearly zero. The FINE capacitance zero control should be set with its pointer straight up before adjusting the COARSE control. the SENSITIVITY control should be set back about 1/2 hour from fully clockwise. Too high a setting will result in unnecessary difficulty in obtaining a null indication: too low a setting will reduce resolution and measuring accuracy.

i. Recheck the TEST signal level, and readjust if necessary.

4.2 MEASURING

a. Complete connection to the test, utilizing appropriate techniques as described in Section 5.

b. Adjust the CAPACITANCE and CONDUCTANCE dials for best null indication on the meter. The null should occur between 100 and 1000 on both the CAPACITANCE and CONDUCTANCE dials. If it occurs above or below these values, the next indicated MULTIPLY C and/or DIVIDE G/ MULTIPLY R range should be used

Note:

Whenever the capacitance <u>or</u> conductance ranges are changed the bridge must be zero balanced as detailed in paragraph 4.1 before measuring.

4.3 INTERPRETING READINGS

a. After balancing both capacitance and conductance to a satisfactory degree of precision, the capacitance of the test specimen is determined directly from the CAPACITANCE dial reading, multiplying by the decimal factor indicated on the MULTIPLY C knob.*

b. The conductance of the test specimen is found by dividing the reading indicated on the G scale of the conductance dial by the factor indicated on the DIVIDE G/MULTIPLY R dial.*

Red dial markings extending from zero to minus 100 have been provided to facilitate the measurement of low loss capacitors, where the null may occur with a conductance dial reading below zero.

*For corrections applying only to measurements made on the XI MULTIPLY CAPACITANCE range and with the test connected directly to the binding posts or coaxial receptacles - see figure 1, page 9.

For information on errors resulting from remote testing see Appendices A, B, and C.

c. Except on the XI Capacitance range, the equivalent shunt resistance is determined by multiplying the reading indicated on the R scale by the factor shown on the DIVIDE G/MULTIPLY R dial. On the XI capacitance range the most accurate procedure is to determine the conductance as outlined in 4.3(b), then take the reciprocal of it to obtain the equivalent shunt resistance. For example, suppose that when using the X1000 DIVIDE G/MULTIPLY R range a CONDUCTANCE dial reading of 50 was observed for a 200 pf mica capacitor. This is, of course, +0.05 μmho. A look at (Fig. 1 page 9) shows that the conductance correction for a 200 pf capacitor would be +0.15 μmho. Adding this to the measured value gives +0.20 μmho as the corrected conductance. The reciprocal of this would be 5 megohms (1/0.0000002 mho). To avoid division, the CONDUCTANCE dial may be convenient to use for conversion from μmhos to ohms. In the above example, the dial reading

CORRECTION FOR THE EFFECTS OF INTERNAL INDUCTANCE AND RESISTANCE

(APPLIES ONLY TO THE X1 CAPACITANCE RANGE AND FOR MEASUREMENTS MADE DIRECTLY AT THE "HI" AND "LO" TEST POSTS OR RECEPTACLES)

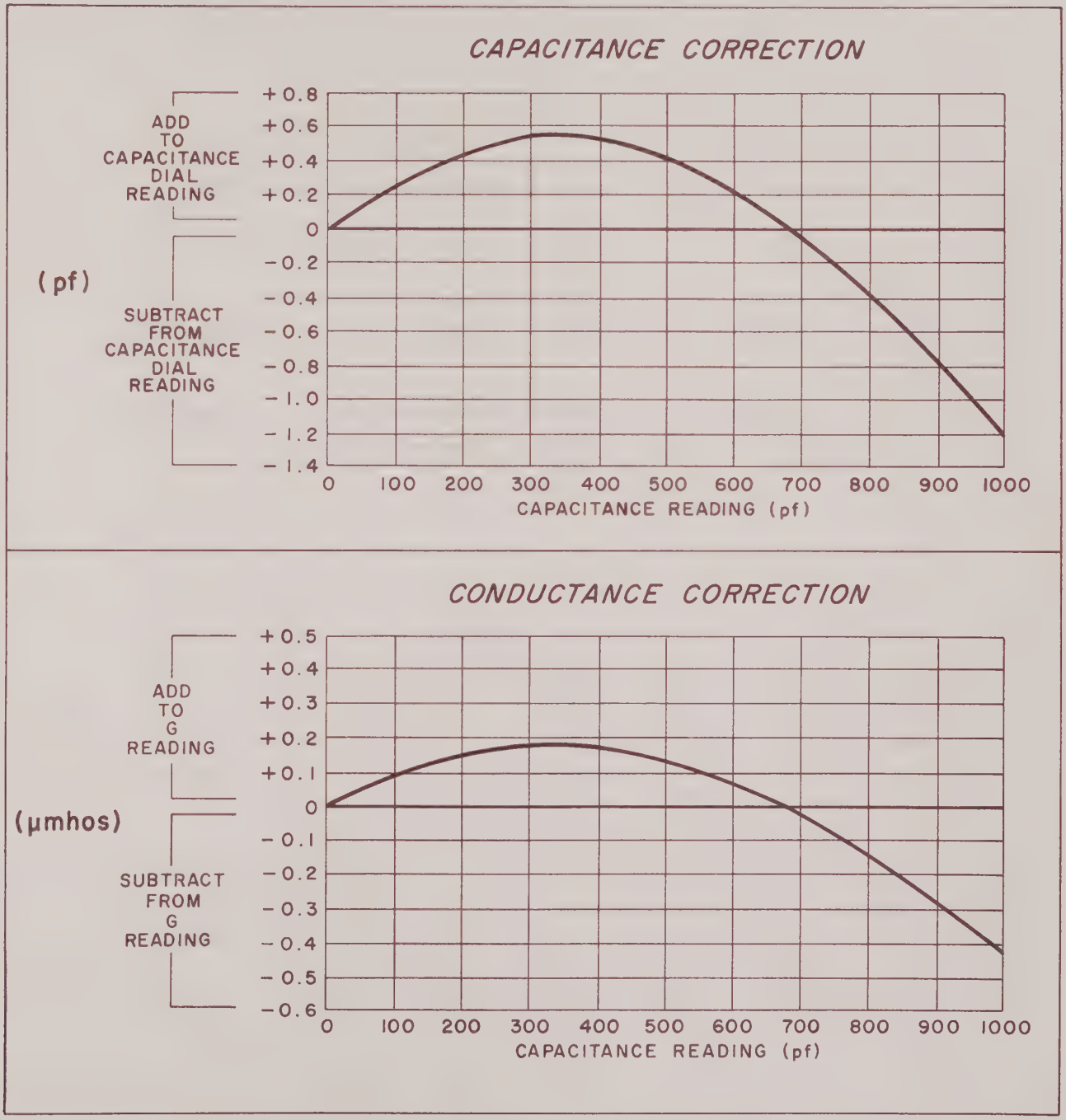

Figure 1

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for the corrected conductance (200) corresponds to 5K on the resistance scale. Multiplying the resistance reading by 1000 (X1000 range) gives the correct figure of 5,000,000 or 5 megohms.

($R = \frac{1 \times 10^6}{G}$ where G is in micromhos).

d. The Q and Dissipation Factor, D, of the test sample may be computed from the following formulae:

$$Q = \frac{2\pi fC}{G} \qquad D = \frac{1}{Q}$$

Therefore at 1 Mc: $Q = 6.28 \frac{C}{G}$

Where C = test specimen capacitance in pf.
" G = test specimen conductance in micromhos.
" f = frequency in megacycles.

SECTION 5

MEASURING TECHNIQUES (See also Appendix A)

5.1 GENERAL

When using a test frequency of 1 Mc, the effect of added lead length between the bridge and the test specimen cannot always be neglected. With large capacitance tests, the resulting error is primarily due to the lead inductance and resistance.

For capacitance values above about 50 pf, increased lead length produces higher readings of both capacitance and conductance. Each foot of extension of the two leads increases the readings approximately as given in Table II.

TABLE II

Capacitance to be measured	Approximate increase in reading for 1 ft. extension of test leads using RG-58/U coaxial cables only.	
	C	G
1000 pf	+ 7 pf	+ 4 μmhos
750 pf	+ 4 pf	+ 2 μmhos
500 pf	+ 1.9 pf	+ 1 μmho
300 pf	+ 0.8 pf	+ 0.4 μmho
100 pf	+ 0.1 pf	+ 0.05 μmho

Below 50 pf the error due to lead inductance becomes less important than that caused by the effects of stray capacitances in the test or connecting cables. If the test is a pure two terminal capacitor (without shunt capacitances from either terminal to ground) the error introduced by measuring on coaxial cables is small (see Graph 1 "Remote Measurement Error Due to Cable Inductance" in Appendix A).

When the test has appreciable capacitance between one of its terminals and ground, that terminal should be connected to the LO TEST receptacle on the bridge. This greatly minimizes errors when measuring fractional pf capacitors. Curve (A) (stray C on LO) and Curve (B) (stray C on HI) of Graph 3 in Appendix A show the importance of this for measurements on a 2.2 pf ceramic capacitor.

The errors resulting from measuring a test having appreciable stray capacitance between both its terminals and ground can become quite large. Curve (C) of Graph 3 shows this error for a 2.2 pf test.

Whenever feasible, the Direct method of measurement should be used because it greatly reduces hand capacitance effects as well as the test specimen position error which are basic limitations when making grounded measurements.

Contact fixtures may be used for production testing provided their residual capacitance does not exceed the range of the COARSE and FINE controls (approx. 10 pf).

5.2 CONNECTION TECHNIQUES FOR DIRECT-CAPACITANCE MEASUREMENTS

1. Measurements at the Bridge

If measurements are to be made at the HI & LO TEST binding posts, the test specimen should be connected as close as possible to these posts. All other conductors in the immediate vicinity of the elements under test must be connected to ground using the GND binding post on the front panel.

In many cases it may be more convenient to insert the wire leads of the test specimen directly into the center conductor receptacle of the HI & LO coaxial TEST jacks. This is particularly useful with smaller mica, ceramic or voltage variable types of capacitors and has the advantage that the outer shell of each jack shields the leads from each other for much of their length.

2. Measurements Using Coaxial Cables

a. With Fixture or Jig

If a fixture or jig is to be used, connect both coaxial leads between it and the bridge before zero balancing.

b. With Shielded Test Equipped with Coaxial Receptacles

When the test is in a metal shield can equipped with coaxial receptacles for connection (as in the BEC CS- Direct Capacitance Standards), connect both coaxial cables to the bridge and the LO one to the test before zero balancing.

c. Open Test Without Shield or Fixture

Connect both coaxial cables to the bridge, strap or solder their braids together at the test end, and connect the LO center conductor to the test before zero balancing. (The center conductor of the HI cable should be kept away from the test).

5.3 CONNECTION TECHNIQUES FOR GROUNDED CAPACITANCE MEASUREMENTS

Grounded capacitance measurements are inherently less accurate than Direct-capacitance measurements owing to unavoidable stray capacitance variations between the HI test lead and ground.

Although these variations may amount to 1 μμf or more, it is usually possible to reduce this uncertainty to less than 0.5 μμf by using the following procedure:

1. Connect the ground side of the test to the LO binding post using a short length of wire.

2. Connect a short length of bare tinned copper wire to the HI binding post. Bend this wire so it approaches the test perpendicularly and is spaced away from all surrounding objects as much as possible. The free end should be spaced approximately 1/4 inch from the high terminal of the sample for bridge zero balance adjustments. The final measurement is made with this wire connected to the test.

5.4 DIFFERENTIAL MEASUREMENTS

In addition to the TEST connections on the front panel, BNC receptacles, marked STD provide access to the standard arm of the bridge.

For either differential or temperature coefficient measurements the reference capacitor is connected to the STD BNC receptacles, and the test specimen to the TEST BNC receptacles. It is desirable to keep the connecting coaxial cables as short as convenient and of equal lengths to both capacitors.

If the reference capacitor is adjusted at the start of the test to equal the one being tested, the bridge can then be set to a capacitance range that will give the desired resolution. For example; if a 100 pF ceramic capacitor with a negative T.C. of 300 P.P.M./°C is to be tested to verify its T.C., a set up can be made with an adjustable air trimmer connected to the STD cables, and the ceramic capacitor may be in a temperature chamber while the air trimmer is kept at a fixed temperature.

The capacitance of the air trimmer can now be set to equal that of the ceramic, and the bridge switched to the X.01 or X.001 capacitance ranges depending on the desired rnage of capacitance change to be observed. If the X.001 range is selected and the T.C. is nominal, a 30°C change of capacitor temperature should result in a 1 pF capacitance change (full scale deflection). Had the X.01 range been selected, coverage would have been 1/10 of full scale.

With the connections previously described, the bridge reading will be direct sensing; that is, an upscale reading indicates an increase of capacitance of the test specimen.

When testing capacitors of 10 pF or less for T.C., an external capacitor on the standard arm is necessary since the C ZERO COARSE and FINE controls can be used for that purpose.

It is best to leave the power on continuously when the greatest possible stability is required for critical T.C. measurements.

For critical differential measurements when the desired information is the exact difference between an unknown and a reference or standard capacitor, the following measuring technique is suggested:

1. Set-up

Connect the reference to the STD receptacles and the test to the TEST receptacles (using equal length coaxial cables). Follow the general procedure given in SECTION 4 "OPERATING PROCEDURE, SET UP AND ZERO BALANCING", except that the MULTIPLY C and DIVIDE G/MULTIPLY R ranges should be selected to best cover the differences to be measured. It may be helpful to balance with the main CAPACITANCE dial at mid-scale or some point other than zero, so that either increase or decrease of capacitance can be measured on-scale. The COARSE and FINE controls have a combined upscale control range of about 10 pf, thus allowing full-scale shift of zero balance on the X.001 MULTIPLY C range, and full or nearly full scale on the X.01 range.

2. Measuring

Connect the HI coaxial leads to the two capacitors and null the bridge with the CAPACITANCE and CONDUCTANCE dials. Record the readings. Reverse the two LO coaxial lead connections, and again null and read.

3. Interpreting Readings

Ideally the two capacitance readings would be in opposite directions from the set-up reading, and by equal amounts. However, due to minor lead unbalances the usual result will be two readings that are not symmetrically offset from the set-up point, and which may both be in the same direction from it. In any case, one half of the difference between readings is the amount by which the two capacitors differ. Also the

difference readings are always direct sensing in that the connection giving the higher reading is the one where the capacitor connected to the TEST receptacles is larger than that on the STD receptacles.
It is worthwhile noting that one of the main advantages of using this method of measuring capacitance differences is that the effects of zero shift in the bridge are eliminated

As a word of caution, this method is most useful for determining very small differences (such as T.C. effects) between rather large capacitors - roughly between 10 and 1000 pf. It can give serious errors when very large and unequal stray capacitances exist from either side of the test or reference capacitor to ground.

SECTION 6

MAINTENANCE

6.1 GENERAL

Tubes need not be replaced until they cease to perform satisfactorily. If there is a question as to performance, new tubes may be substituted to check for improvement, or they may be checked on any good tube tester.

No tube selection is necessary.

The 6C4 1 Mc oscillator tube is accessible by removing the top cover of the oscillator shield. When replacing this cover be sure to tighten the holding screws to prevent leakage.

6.2 NORMAL OPERATING VOLTAGES

TABLE 4

Conditions:
115v 60∿ line input
OSC LEVEL switch on HI, OSC LEVEL ADJUST fully clockwise.
Bridge balanced.

Equipment:
Ac/Dc Multimeter with dc sensitivity of 20,000 ohms/v.
RF Voltmeter, such as Boonton ELECTRONICS Corporation Model 91C.

From:	To:	Normal Rdg.
V5 (6X4) Pin 7 (cathode)	chassis	270-290v dc
V6 (0A2) Pin 5 (plate)	chassis	145-155v dc
V1 (6C4) Pin 5 (plate)	chassis	220-240v dc
V2,3,4:		
" (6AU6) Pin 5 (plate)	chassis	230-260v dc
" " Pin 6 (screen)	chassis	130-150v dc
" " Pin 3 (heater)	Pin 4	6.0-6.6v ac (60∿)
J1 Oscillator output.	chassis	1.0-1.5v ac (1 Mc)

6.3 1 MC OSCILLATOR AND DETECTOR CHECKS AND ADJUSTMENT

1. Overall Check

The overall operation of the oscillator and detector may be conveniently tested by a check of NULL INDICATOR meter deflection for a specified amount of bridge unbalance.

To do this, switch to DIRECT, X1000, and X.001. Turn the SENSITIVITY control fully on and turn the CAPACITANCE and CONDUCTANCE dials to zero. Carefully balance the bridge, using the C ZERO and R/G ZERO controls.

Turning the CAPACITANCE dial 1 pf (effective change being 0.001 pf) in either direction from balance should produce an increase in NULL INDICATOR meter reading of at least 30 μa.

If less change in meter reading is obtained, the oscillator and/or detector may require re-alignment.

2. Oscillator Frequency

The oscillator frequency has been factory adjusted to be within a few Kc of nominal If it is necessary to re-adjust the frequency, it should be done with the oscillator connected normally to the bridge, which has been allowed to warm up for at least one half hour.

Any standard method of determining frequency may be used, such as a frequency counter or crystal calibrator, connected to the LO TEST receptacle.

Next connect an RF Voltmeter (suitable for use at 1 Mc) to the LO TEST coaxial receptacle. Switch the OSC LEVEL toggle switch to the LO position. Using an insulated tuning tool, adjust the FILTER ADJ control on the oscillator shield can for maximum reading on the RF VTVM. Normal is about 1 v. Re-check, and if necessary reset the oscillator frequency. Restore the OSC LEVEL switch to the HI position.

3. Detector Alignment

To re-align the detector circuits, switch to DIRECT, X1000, and X.001. Turn the CAPACITANCE and CONDUCTANCE dials to zero and the SENSITIVITY control fully on. Balance the bridge using the C ZERO and R/G ZERO controls.

Unbalance the bridge for a meter reading of about 25 μA, then peak each circuit of T7, T6, T5, and T4 for maximum meter reading (keep the meter at about 25 μA by nearly balancing the bridge).

Repeating the overall check (step 6.3.1) should now give at least a 30 μA reading per dial pF.

4. Detector Sensitivity

If low detector sensitivity is suspected, it can be checked with a well shielded signal generator having low output impedance and a calibrated attenuator. Connect the generator by coaxial cable to J2. With the SENSITIVITY control fully clockwise, determine the input level required for a NULL INDICATOR meter reading of 25 μA. Normal input level is approximately 0.5 microvolt.

SECTION 7

CALIBRATION

7.1 GENERAL

This capacitance bridge has been calibrated at the factory by trained specialists using equipment developed especially for the purpose.

Many of the calibration steps must be performed in strict sequence, and use of accurate three-terminal capacitance standards is mandatory.

No re-calibration should be attempted by the customer.

Calibration accuracy is not affected by removing the instrument from the cabinet or by replacing tubes, but the sealed bridge unit should not be opened.

7.2 CHECKING CAPACITANCE CALIBRATION

When calibration must be checked, accurate three-terminal standards such as the BEC Model CS type should be used, and proper technique is essential for accurate results.

Before checking, the bridge should be allowed to reach thermal stability (8 hour warm-up), and the standards should be at room temperature (preferably 25°C).

The shortest practical coaxial cables should be used for connecting the standards to the bridge since at 1 Mc the effects of their inductance cannot be neglected. Appendix B should be consulted for a detailed discussion of this problem.

When connecting the standard, both cables should be connected to the bridge and the LO cable to the standard, before zero balancing the bridge. The HI cable should then be connected to the standard and the measurement made.

Figure 1, Page 9 gives corrections that should be applied to the readings of capacitance standards to compensate for the effects of lead inductance inside the bridge. These apply only on the X1 capacitance range. They do not include allowance for the inductance of the coaxial cables between the bridge and the standard.

Refer to Appendix B for a more detailed treatment of this area.

7.3 CHECKING CONDUCTANCE CALIBRATION

To check the operation of the conductance measuring circuits, first set the DIVIDE G/MULTIPLY R and the MULTIPLY C switches at 1 and the CAPACITANCE dial at zero. The R/G ZERO control should be set near mid-rotation.

Next, balance the bridge using the COARSE and FINE C-ZERO controls, and the main CONDUCTANCE dial. Balance should be reached with the CONDUCTANCE dial at or near zero (within ONE DIAL DIVISION, i.e. ± 10 μmhos).

With the CONDUCTANCE dial left at the setting that yielded balance on the X1 DIVIDE G/MULTIPLY R range, it should be possible to achieve a conductance balance on all other DIVIDE G/MULTIPLY R ranges using only the R/G ZERO control and the COARSE and FINE C-ZERO controls. (Do not connect any cables or test fixtures to the bridge while making this test).

A quick test of operation on all DIVIDE G/MULTIPLY R ranges may be performed using 1K, 10K, 100K and 1 megohm, 1/4 watt, ± 1% deposited carbon resistors.

a. First, set up the bridge as detailed in the first two paragraphs. Then insert the wire leads of the 1K resistor into the centers of HI and LO TEST coaxial receptacles and balance the bridge using the CONDUCTANCE and CAPACITANCE dials. Read the indicated value on the CONDUCTANCE dial.

b. Remove the 1K resistor, switch to "10" on the DIVIDE G/MULTIPLY R control, turn the main CAPACITANCE and CONDUCTANCE dials to zero and re-balance using the R/G ZERO controls and the COARSE and FINE capacitance controls. Connect the 10K resistor and again balance using the CONDUCTANCE and CAPACITANCE dials. Read the indicated resistance value on the CONDUCTANCE dial and multiply by 10.

c. Repeat the same procedure on the X100 and X1000 ranges, using the 100K and 1 megohm resistors respectively. In all cases readings should fall within ± 11% of full scale on the CONDUCTANCE dial.

OPERATION WITH EXTERNAL OSCILLATOR AND DETECTOR

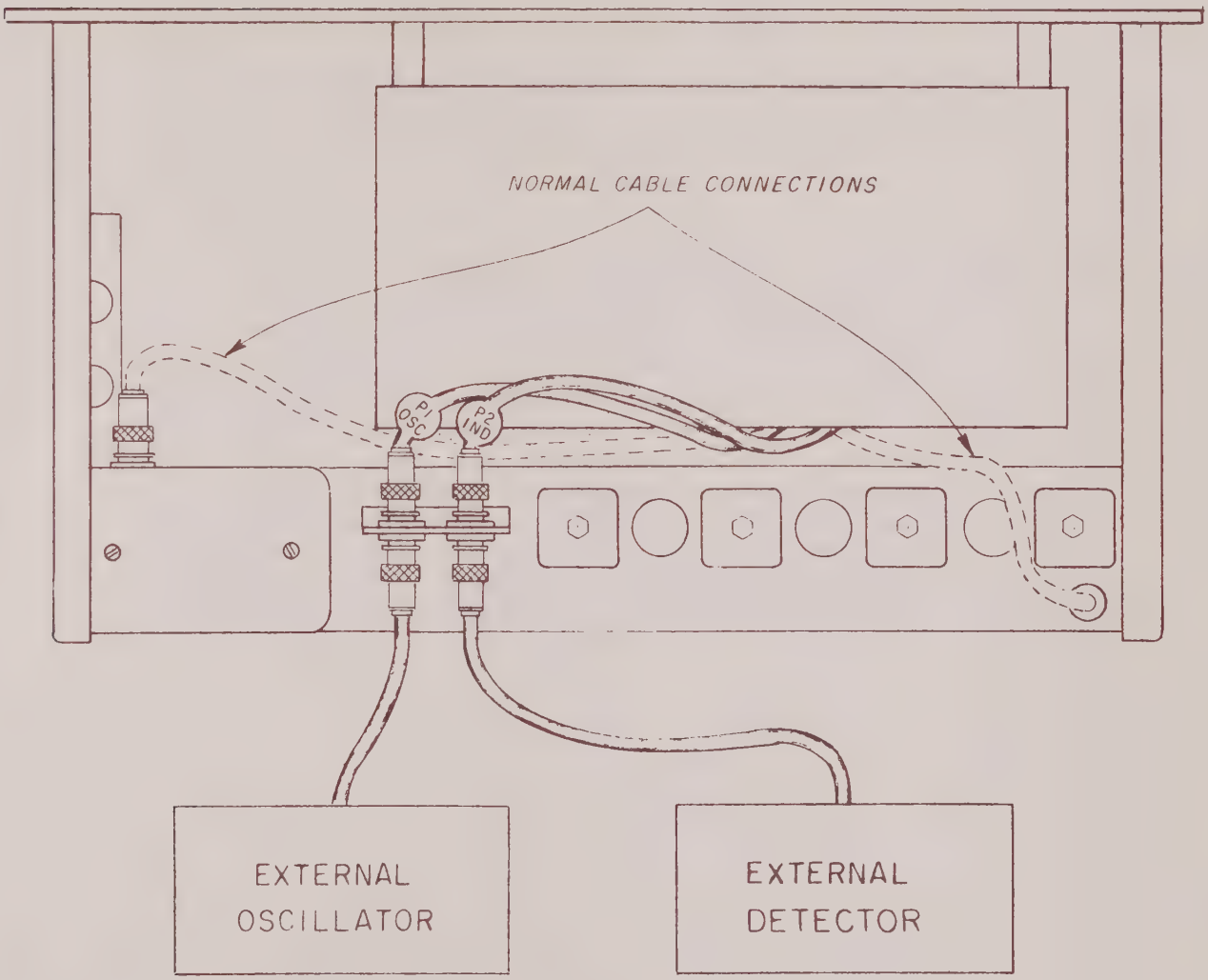


FIGURE 2

CONNECTIONS FOR USE WITH EXTERNAL OSCILLATOR AND DETECTOR.

8.1 OSCILLATOR REQUIREMENTS

An external oscillator to be used with the 75A should cover the desired operating frequency, be capable of delivering at least 1V into a 16 Ω load, have a low internal impedance, and be well shielded to avoid direct pick-up by the indicator.

Harmonic distortion need not be very low except when the 75A is to be used for testing semiconductors. For this use it should not exceed 1% and preferably 0.1%.

8.2 DETECTOR REQUIREMENTS

An external detector for use with the 75A must have high gain at the test frequency, good signal-to-noise ratio, and good shielding against external pick-up. If a receiver is used, it may have a B.F.O. for the indication of an unmodulated signal, or may be used with a tone modulated oscillator.

Although it may be omitted in many cases, a simple matching transformer is desirable between the low impedance of the bridge output transformer and the receiver input. Proper matching will increase the usuable detector sensitivity and give greater measuring resolution.

APPENDIX A

SOME COMPARISONS BETWEEN CAPACITANCE MEASUREMENT ERRORS AT 100 KC AND 1 MC

A. GENERAL

Use of 100 Kc as the test frequency offers considerable advantage in several areas which include:

1. Measurements above 100 pf, whether remotely or at the bridge.

2. Practically all remote measurements when appreciable capacitance exists between either HI or LO TEST post and ground.

3. All measurements when the test itself is not a simple two-terminal capacitor, but has capacitance from either or both terminals of the test to other elements.

Figure A-1 shows the recommended set-up procedure for making remote measurements.

B. ERRORS DUE TO LEAD INDUCTANCE

Above about 100 pf the use of 100 Kc as the test frequency greatly reduces the error due to the inductance of leads connecting the bridge to the test.

Graph 1 shows the added error due to lead inductance when 1 foot long RG-58/U coaxial cables are added between the bridge and the test capacitor. It is apparent that at 100 Kc this error is about 100 times less than at 1 Mc.

It should be noted that Graph 1 does not give total measurement errors - only the increase in reading per foot of the specified coaxial cables. At 1 Mc, the inductance of leads internal to the bridge can and does contribute appreciable error. (See Table on next page for average errors in the 75A at 1 Mc due to internal inductance).

This error, of course, is present whether open wire leads or coaxial cable are used to connect the test to the bridge.

C. ERRORS DUE TO COAXIAL CABLE CAPACITANCE

Below about 50 pf the capacitance between the center conductor and outer braid of the coaxial cables causes an increase in capacitance reading. This effect is generally negligible at 100 Kc, but appreciable at 1 Mc. Graph 2 shows the approximate magnitude of this error. Note that the error is not a constant percent-per-foot; instead it becomes greater the longer the cables.

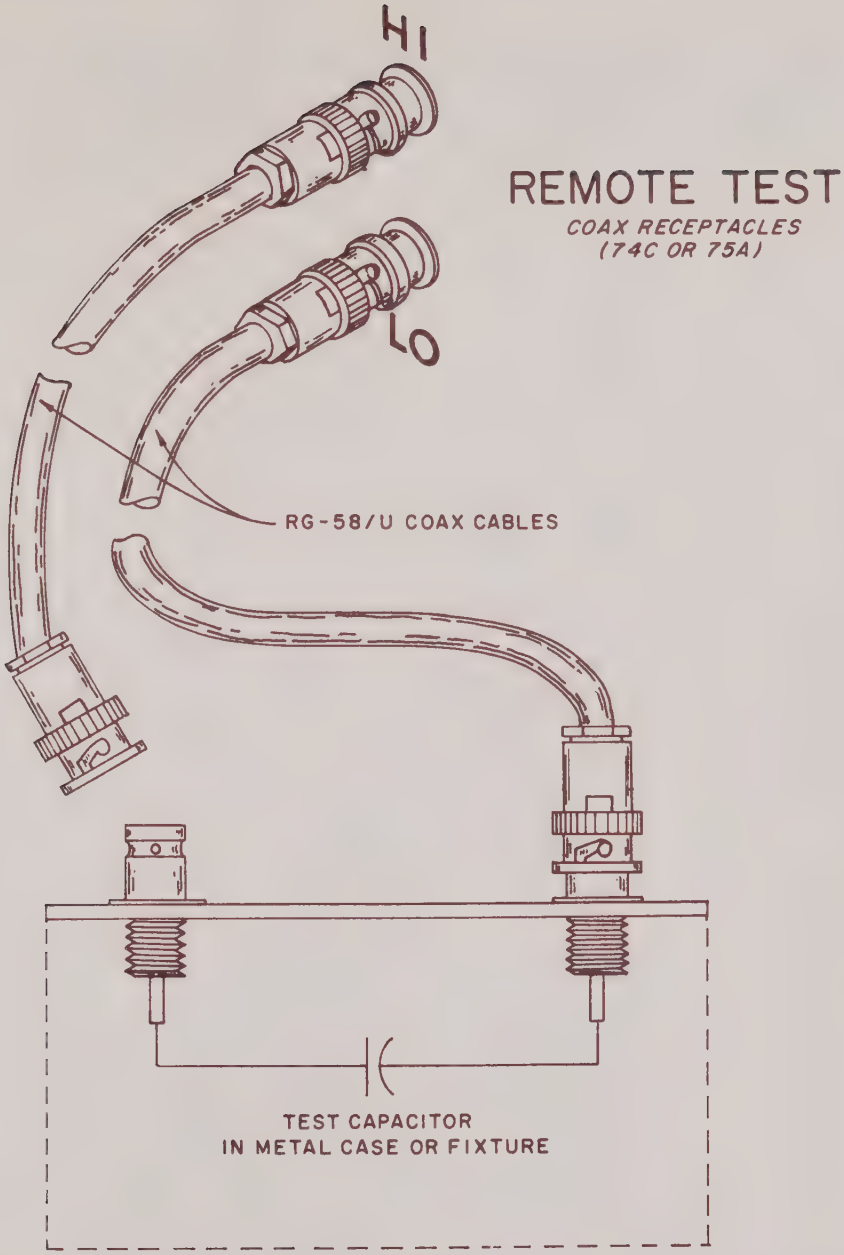
D. ERRORS DUE TO MEASURING OTHER THAN A SIMPLE TWO-TERMINAL TEST

Graph 3 shows representative errors when measuring a 2.2 pf ceramic capacitor in the presence of capacitance between the LO side of the test and ground (cable braid); the HI side and ground; and with equal values from both sides to ground.

75A CAPACITANCE BRIDGE AT 1 MC

CORRECTIONS FOR INTERNAL INDUCTANCE: X1 CAPACITANCE RANGE ONLY

CAPACITANCE DIAL READING (pf)	50	100	200	300	400	500	600	700	800	900	1000
ADJUST READING BY ADDING: (pf)	+.15	+.28	+.42	+.55	+.52	+.41	+.26	0	-.4	-.8	-1.2



SETUP FOR REMOTE MEASUREMENT OF CAPACITORS USING COAXIAL CABLES (DIRECT ONLY)

PROCEDURE:

1. *Connect both cables to the bridge, and connect the* LO *cable to the case receptacle of the test that has the greatest capacitance to case (if any).*

2. *Balance the bridge*

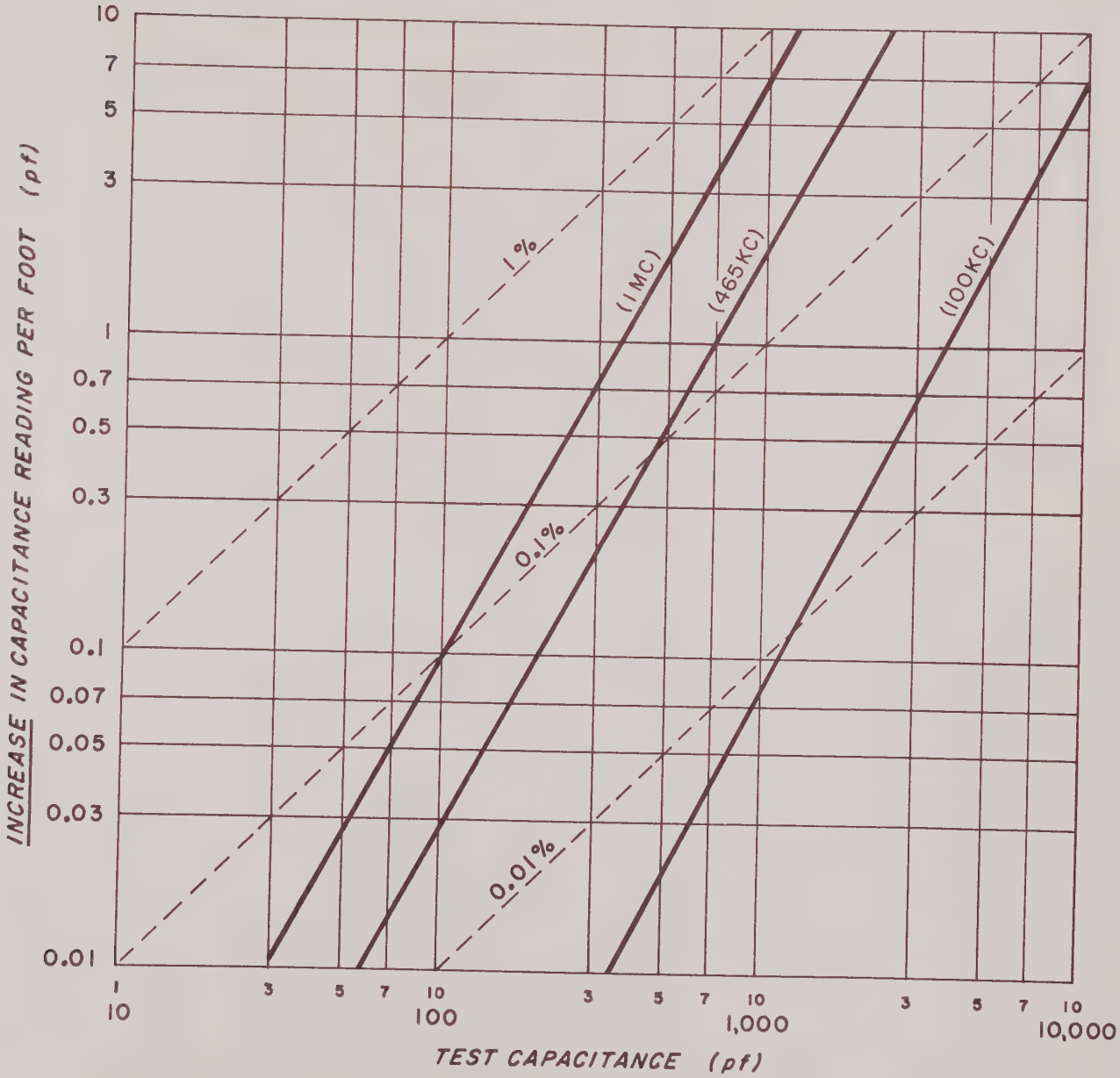
3. *Connect the* HI *cable to the other case receptacle and measure.*

Figure A1

(830,070A)

REMOTE MEASUREMENT ERROR DUE TO CABLE INDUCTANCE

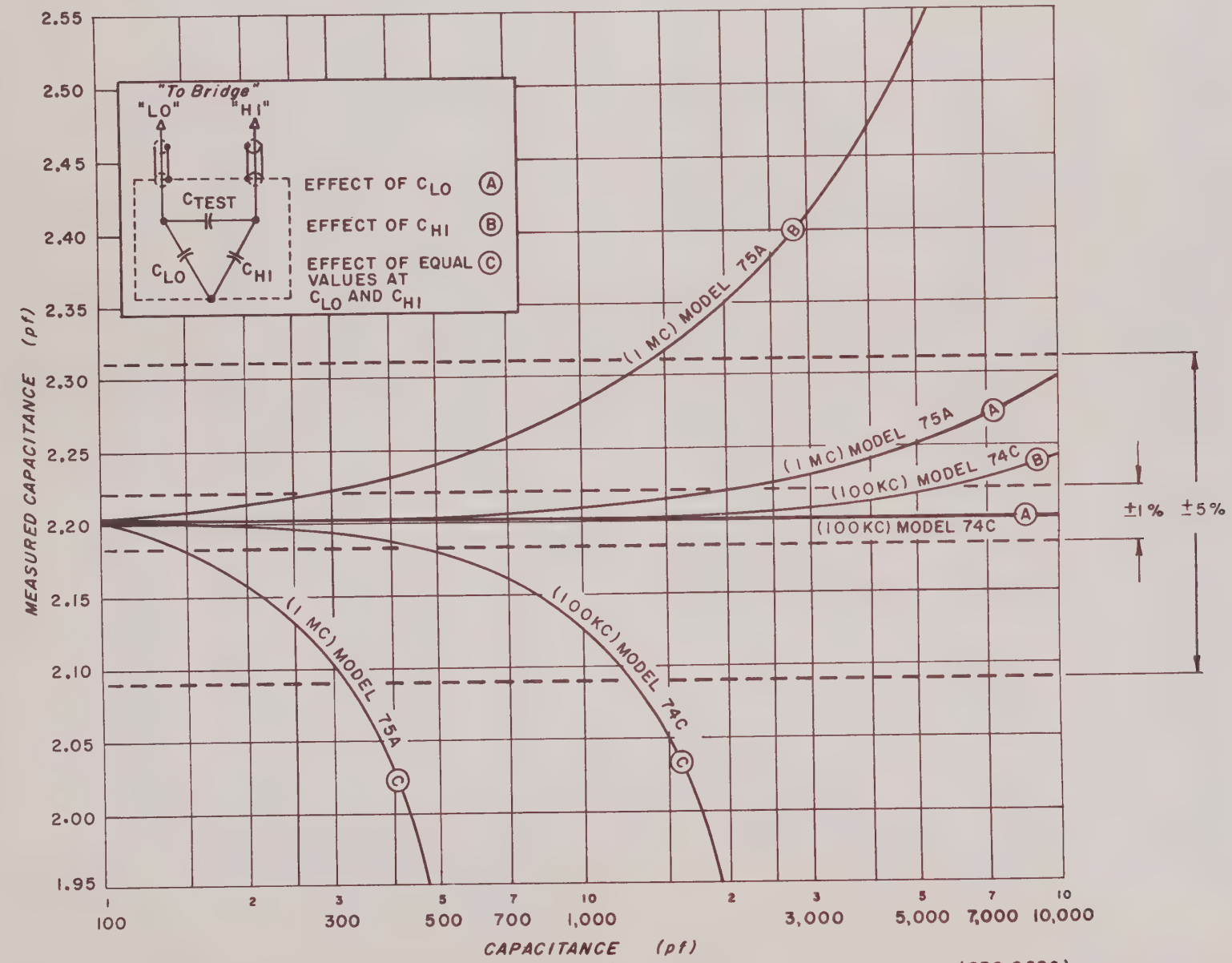
(INCREASE IN CAPACITANCE READING PER FOOT OF RG-58/U CABLES)



Graph 1

(830,067C)

REPRESENTATIVE ERRORS WHEN MEASURING A 3-TERMINAL CAPACITOR



Graph 3

(830,069C)

APPENDIX B

THE USE OF CAPACITANCE STANDARDS LARGER THAN 100 pf FOR CHECKING CAPACITANCE ACCURACY ON THE X1 CAPACITANCE RANGE OF THE 75A AT FREQUENCIES ABOVE 100 KC.

INTRODUCTION

At 1 Mc lead inductance effects become the limiting factor in making accurate capacitance measurements above approximately 100 pf. This paper offers specific suggestions for minimizing errors from this source.

In the design of the 75A great care was taken to minimize internal inductance, with the final design having less than 0.25% error in reading between 100 and 1000 pf without the use of a correction chart, provided the test is connected directly at the HI and LO TEST binding posts or directly at the centers of the TEST coaxial receptacles. The internal inductance errors may be further minimized by applying the corrections given in the Table below.

75A CAPACITANCE BRIDGE AT 1 MC

CORRECTION AT 1 MC FOR INTERNAL INDUCTANCE: X1 CAPACITANCE RANGE ONLY

CAPACITANCE DIAL READING (pf)	50	100	200	300	400	500	600	700	800	900	1000
ADJUST READING BY ADDING: (pf)	+.15	+.28	+.42	+.55	+.52	+.41	+.26	0	-.4	-.8	-1.2

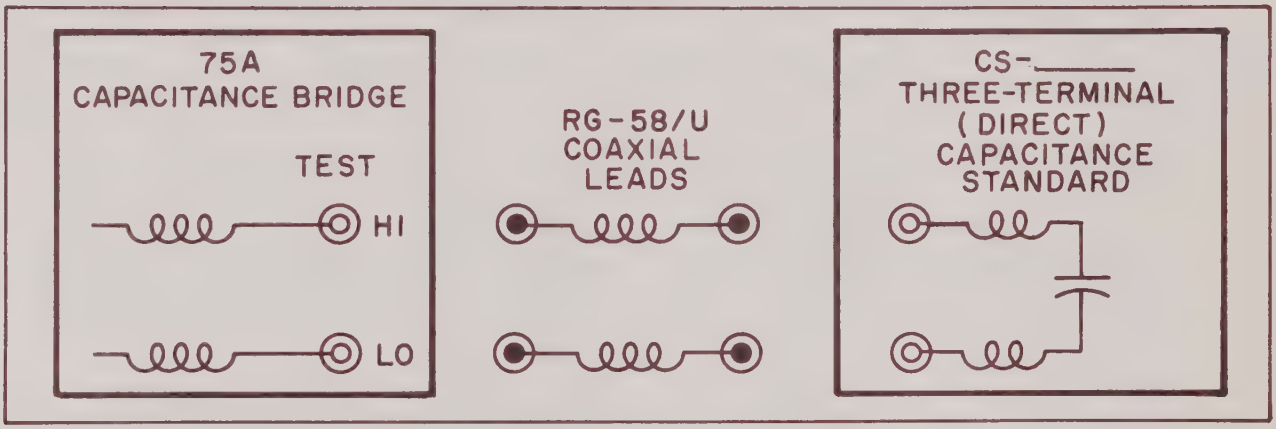
It has been our policy to recommend that our 1 Mc bridges be returned to us for calibration checks, since we have both the trained personnel and the specialized equipment to do an accurate job.

When the customer elects to perform the checking of the bridge calibration, we recommend that the X1 capacitance range

(100 to 1000 pf) be checked initially at 100 Kc, thus eliminating the need to consider the effects of inductance in the bridge, in the coaxial leads, or in the standard.*

If the calibration is found to be within specifications at 100 Kc it may then be checked at 1 Mc, with the knowledge that differences between readings at the two frequencies are directly attributable to the effects of inductance in the bridge, the leads, or the Standards. (See Figure 1)

FIGURE I



* A suitable 100 Kc unit designated "75-2A 100 Kc Oscillator/ Detector Unit", is available. It is mechanically and electrically interchangeable with its 1 Mc counterpart in the 75A, and is supplied pre-aligned and ready for use without adjustment.

Typical test results for a setup using a 75A, RG-58/U coaxial leads, and type CS-____ Capacitance Standards are given in Table 2.

TABLE 2

CS-___ Three-Terminal Capacitance Standard	Nameplate Value (pf)	75A CAPACITANCE READINGS USING RG-58/U COAXIAL CABLES					
		Cable Length 3-1/2 inches			Cable Length 9-1/2 inches		
		@ 100Kc	@ 465 Kc	@ 1 Mc	@ 100Kc	@ 465Kc	@ 1 Mc
CS-1000	1000.4	1000.1	1001.0	1003.9	1000.1	1001.7	1007.4
CS-750	743.9	743.8	744.05	745.4	743.8	744.6	747.4
CS-500	499.7	499.8	499.8	500.05	499.8	500.05	501.0
CS-300	299.7	299.85	299.8	299.6	299.85	299.9	300.0
CS-100	100.00	99.75	99.64	99.45	99.75	99.64	99.51

The Comparative data in Table 2 for measurements made using 3-1/2 inch and 9-1/2 inch RG-58/U coaxial leads shows that a 1 Mc it is impossible to measure a 1000 pf standard without incurring lead inductance errors. Each inch of increase in the length of the cables is shown to cause a 0.6 pf (0.06%) increase in the reading.

Table 3 interprets the data in Table 2 in terms of the increase in capacitance reading per inch and per foot of cable extensions. (See also Graph 1 of APPENDIX A)

TABLE 3

INCREASE IN CAPACITANCE READING DUE TO INDUCTANCE OF RG-58/U COAXIAL CABLES.					
Value of Capacitance Standard	At 1 Mc		At 465 Kc		At 100 Kc
	Per ft. of cable	Per inch of cable	Per ft. of cable	Per inch of cable	
1000 pf	7 pf	0.58 pf	1.4 pf	0.12 pf	(Negligible error - no correction required)
750 pf	4 pf	0.33 pf	1.1 pf	0.09 pf	
500 pf	1.9 pf	0.16 pf	0.5 pf	0.04 pf	
300 pf	0.8 pf	0.066 pf	0.2 pf	0.017 pf	
100 pf	0.1 pf	-	-	-	
(Subtract to Correct)					

TO SUMMARIZE:

1. The effects of lead inductance <u>inside the 75A</u> are small enough that at 1 Mc specified accuracy is met without using corrections - provided the capacitor to be measured is connected directly at the HI and LO TEST binding posts or TEST coaxial receptacles. If greater accuracy is required, apply the corrections given in Table 1 to correct for internal inductance effects.

2. The capacitance accuracy on the X1 range of the 75A should preferably be checked at 100 Kc.

3. For capacitance measurements at 1 Mc above 100 pf, correction <u>must</u> be made for the effects of the coaxial leads used between the test and the bridge, and may be figured from Table 3.

AN EXAMPLE:

A 75A is to have its capacitance accuracy checked on the X1 Capacitance range at 1 Mc, using 100, 500 and 1000 pf type CS-___ Capacitance Standards connected to the bridge with 6 inch RG-58/U coaxial cables.

If no 100 Kc Oscillator/Detector unit is available, a fairly accurate check can still be made by measuring the Standards at 1 Mc, and applying both the corrections from Table 1 and Table 3 of this paper. The corrected readings should fall well within the bridge guarantee specifications.

(1)	Standard: CS-___	"100"	"500"	"1000"
(2)	Certified (Nameplate) Value of Standard	100.01 pf	500.26 pf	1000.4 pf
(3)	Reading on 75A with 6" RG-58/U Coax. leads	99.8 pf	500.7 pf	1005.4 pf
(4)	Correction from Table 1	+0.28 pf	+0.41 pf	-1.2 pf
(5)	Correction from Table 3	-0.05 pf	-0.95 pf	-3.5 pf
(6)	Net correction (4) + (5)	+0.23 pf	-0.54 pf	-4.7 pf
(7)	Corrected reading (3) + (6)	100.03 pf	500.16 pf	1000.7 pf
(8)	Bridge Calibr. Error (7) vs. (2)	+0.02 pf	-0.1 pf	+0.3 pf
(9)	Guarantee Tolerance ± (0.25% + 0.5 pf) on X1 Range	±0.75 pf	±1.75 pf	±3.0 pf

APPENDIX C

THE MEASUREMENT OF "LOSSY" CAPACITORS

To accurately measure the capacitance of "lossy" capacitors (those with equivalent parallel resistance in the general region between 1000 Ω and 1 megohm) it is necessary to construct and use a set of correction curves for each individual bridge.

To do this, acquire a set of deposited carbon resistors (Mepco 1/4 W Type C10 is recommended) with values ranging between 1000 Ω and 1 megohm. Measure* each of the resistors on the bridge and plot the capacitance readings, preferably on semi-log graph paper. Use their true capacitance (0.07 pf for Mepco 1/4 W Type C10) as the zero reference for determining the magnitude and direction of the bridge error.

Typical data is shown in the following table:

(For illustration only - do not use unless verified)

	Resistor (Ω)	Bridge Reading (1)	True Value (2)	Indicated Correction (1) - (2) with sign inverted
X1 DIVIDE G/ MULTIPLY R range	1 K	-0.33 pf	+0.07 pf	+0.40 pf
	1.2 K	0.00	"	+0.07
	1.5 K	+0.11	"	-0.04
	2 K	+0.26	"	-0.19
	3 K	+0.22	"	-0.15
	5 K	+0.20	"	-0.13
	10 K	+0.10	"	-0.03
X10 DIVIDE G/ MULTIPLY R range	10 K	+0.35 pf	+0.07 pf	-0.28 pf
	12 K	+0.39	"	-0.32
	15 K	+0.35	"	-0.28
	20 K	+0.30	"	-0.23
	30 K	+0.22	"	-0.15
	50 K	+0.14	"	-0.07
	100 K	+0.10	"	-0.03
X100 DIVIDE G/ MULTIPLY R range	100 K	+0.088 pf	+0.07 pf	-0.018 pf
	120 K	+0.091	"	-0.021
	150 K	+0.085	"	-0.015
	200 K	+0.078	"	-0.008
	300 K	+0.068	"	+0.002
	500 K	+0.064	"	+0.006
	1 Meg	+0.07	"	0.00

75C
a

Note that the capacitance error does not depend on the capacitance value of the test, but on its resistive component. Hence for any given value of equivalent resistance it is what might be called a "fixed pf" error, the effect on the test varying in percentage with the size of the test capacitance.

For example, if the test consisted of a capacitor with equivalent parallel resistance of 5000 Ω and a true capacitance of .5 pf (such as might be found in semiconductor work) the measured C would be about .63 pf. If not corrected this would represent an error of about 25% from true. If the true capacitance had been 5 pf, however, the error would have been only about 2.5%.

* Connect by pushing their leads (cut to approximately 3/4 inch long on each end) into the centers of the HI and LO coaxial TEST receptacles of the bridge.

CAPACITANCE/LOSS FORMULAS

IN TERMS OF → / TO OBTAIN ↓	D	Q	G	R_s	R_p	Ø	Θ
D =		$\frac{1}{Q}$	$\frac{G}{\omega C}$ / $X_c G$	$\omega C R_s$ / $\frac{R_s}{X_c}$	$\frac{1}{\omega C R_p}$ / $\frac{X_c}{R_p}$	TAN Ø	COTAN Θ
Q =	$\frac{1}{D}$		$\frac{\omega C}{G}$ / $\frac{1}{X_c G}$	$\frac{1}{\omega C R_s}$ / $\frac{X_c}{R_s}$	$\omega C R_p$ / $\frac{R_p}{X_c}$	COTAN Ø	TAN Θ
G =	$\omega C D$ / $\frac{D}{X_c}$	$\frac{\omega C}{Q}$ / $\frac{1}{Q X_c}$		$(\omega C)^2 R_s$ / $\frac{R_s}{X_c^2}$	$\frac{1}{R_p}$		
R_s =	$\frac{D}{\omega C}$ / $D X_c$	$\frac{1}{\omega C Q}$ / $\frac{X_c}{Q}$	$\frac{G}{(\omega C)^2}$ / $G X_c^2$		$\frac{1}{(\omega C)^2 R_p}$ / $\frac{X_c^2}{R_p}$		
R_p =	$\frac{1}{\omega C D}$ / $\frac{X_c}{D}$	$\frac{Q}{\omega C}$ / $Q X_c$	$\frac{1}{G}$	$\frac{1}{(\omega C)^2 R_s}$ / $\frac{X_c^2}{R_s}$			

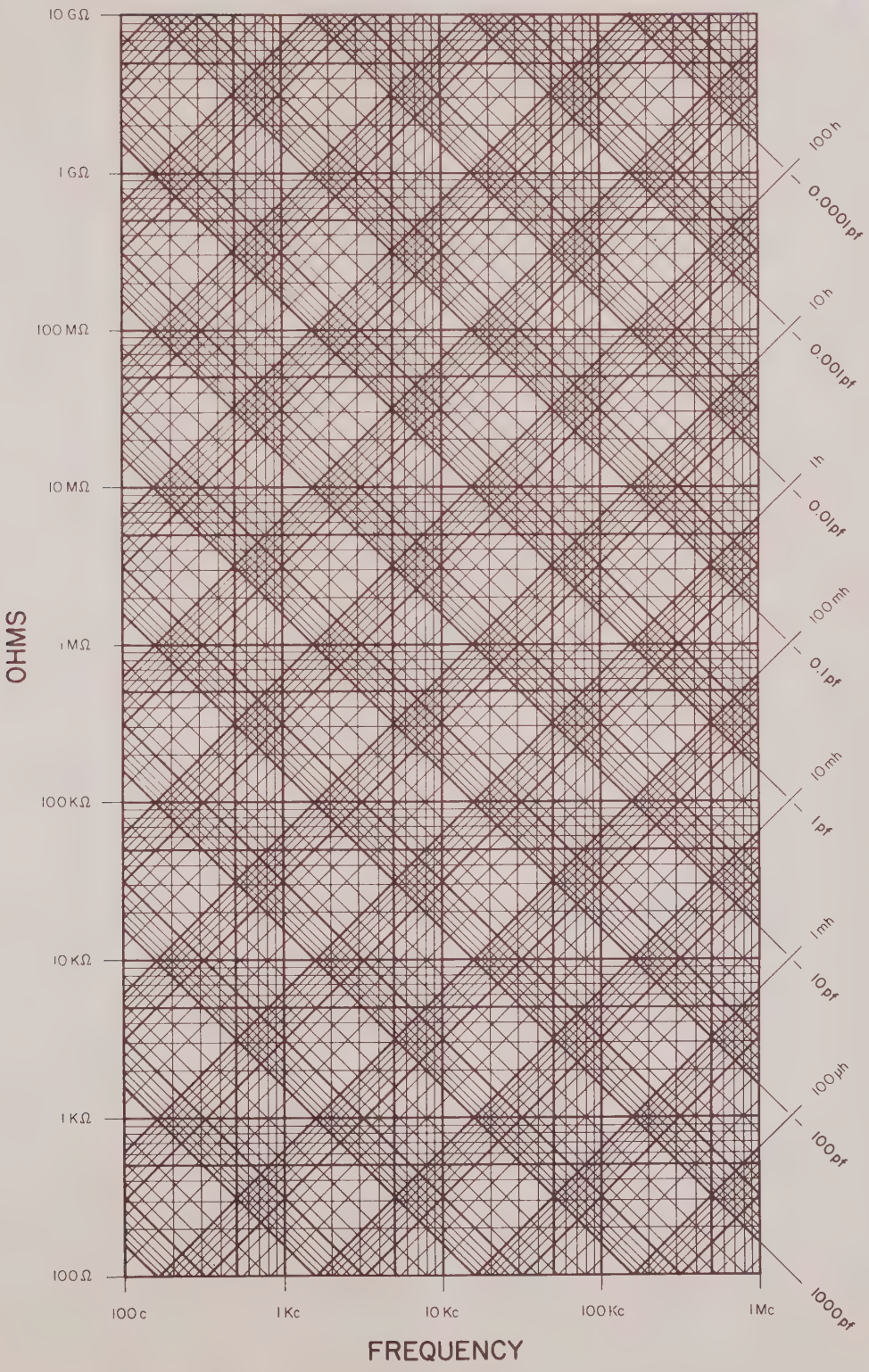
The angle Ø in radians, by which the current fails to lead the voltage by 90°, is very nearly equal to the power factor for P.F.'s of 10% or less. It is also approximately equal to the dissipation factor, D, but at large angles of Ø, D departs more rapidly than P.F.

$$P.F. = \frac{R_s}{Z} = \frac{1}{\sqrt{1+Q^2}} = \cos\Theta$$

$$\text{if } Q \geq 10, \quad P.F \approx \frac{1}{Q} = D$$

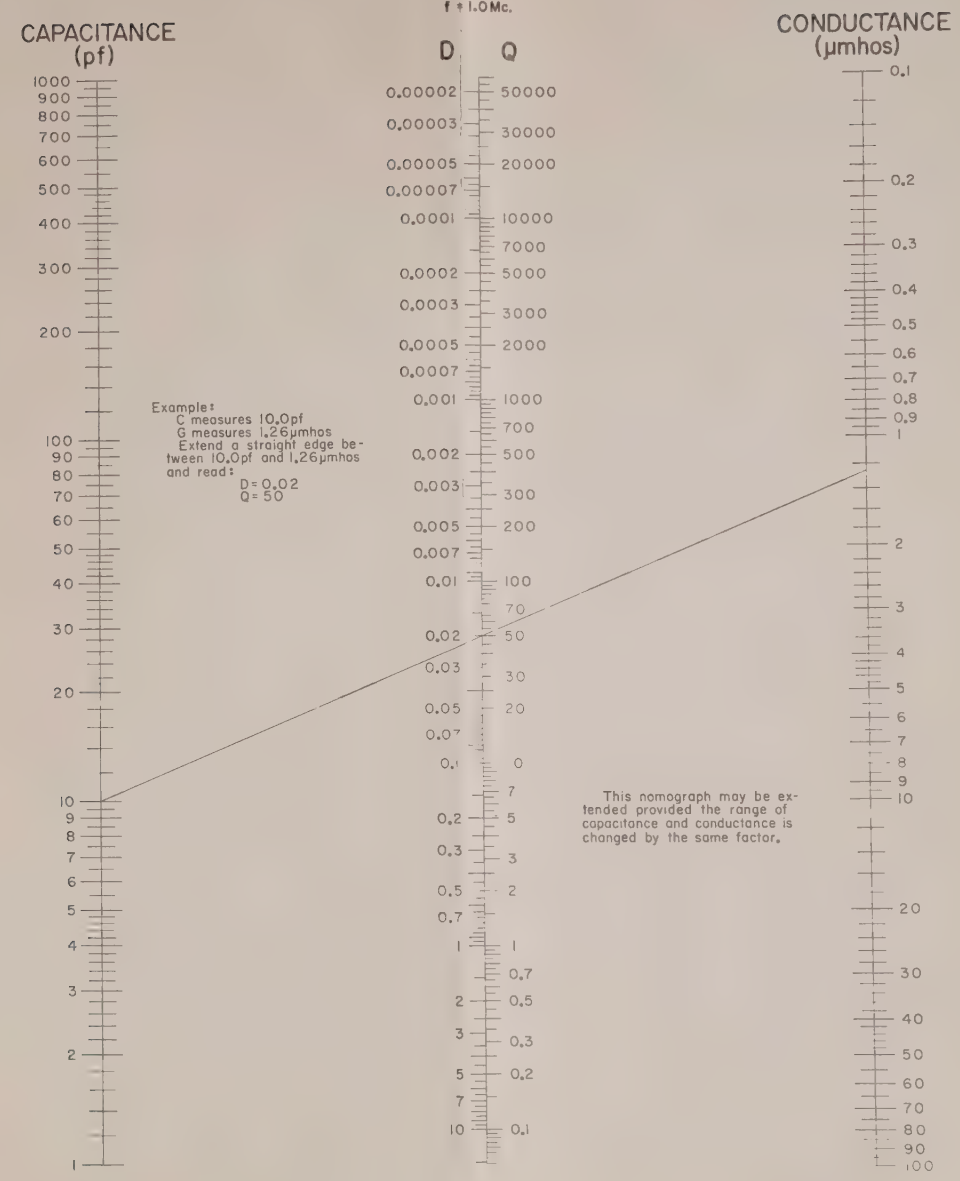
Calibration Copy

CAPACITANCE BRIDGE REACTANCE CHART



Nomograph for D or Q of Capacitors

f = 1.0Mc.



SECTION 9

WARRANTY

Boonton ELECTRONICS Corporation guarantees to the original purchaser that each instrument it manufactures will be free from defects in material and workmanship for a period of one year after date of initial shipment. Our liability is limited to repairing or replacing any defective part with the exception of vacuum tubes, panel lamps, fuses, choppers, and batteries. The warranty lapses if, upon our examination, we judge that the instrument has been abused in any way.

PROCEDURE TO FOLLOW IF THERE IS DIFFICULTY WITH THE INSTRUMENT

1. Call our plant or our representative nearest you. A simple solution may result from discussion of the problem with our trained personnel.

2. If the fault is not readily eliminated, prepare the instrument for return to us. Pack carefully in a sturdy container using several inches of shock absorbing material on all six sides of the instrument. Include all probes, cables, or accessory units. On all paper work pertaining to the returned instrument, note the model and serial number and state briefly the details of the fault. Ship to us transportation charges prepaid.

3. If the instrument is within the warranty, we will repair and return to you transportation charges prepaid. If the instrument is beyond the one year warranty period, we will repair and return it unless approval of a cost estimate is requested. If the instrument is within the one year warranty period, but our examination reveals abuse, we will await approval of our cost estimate before proceeding with repairs.

SECTION 10

BIBLIOGRAPHY

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3. "Direct Capacity Measurements", G. A. Campbell,
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4. "The Precise Measurement of Small Capacitances",
   A. M. Thompson
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SECTION 11

TABLE OF REPLACEABLE PARTS

NOTE:

Components in the "Bridge" unit have not been included, since in general their replacement must be followed by adjustments that require specialized equipment and techniques.

- CAPACITORS -

	Description			BEC Part No.
C1	Sil. Mica	56 pf ± 1% 500V	Arco DM15F560F	200,003
C2	Cer. Zero T.C.	3.3 pf ± 0.25 pf	CRL TCZ-3R3	224,105
C3	Met. Mylar	0.047 μf ± 10% 400V	Goodall X663FR	236,002
C4	Met. Mylar	0.047 μf ± 10% 400V	Goodall X663FR	236,002
C5	Met. Mylar	0.047 μf ± 10% 400V	Goodall X663FR	236,002
C6	Met. Mylar	0.1 μf ± 20% 400V	Goodall X663FR	236,001
C7	Met. Mylar	0.1 μf ± 20% 400V	Goodall X663FR	236,001
C8 thru C19	(in "Bridge" unit)			
C20	Sil. Mica	5100 pf ± 5% 500V	Arco DM20F512J	200,006
C21 thru C26	(not used)			
C27	Sil. Mica	100 pf ± 5% 500V	Arco DM15F101J	200,001
C28	Mylar	0.1 μf ± 20% 200V		230,116
C29	Met. Paper	0.1 μf ± 20% 200V		230,136
C30	Mylar	0.01 μf ± 20% 400V		234,021
C31	Mylar	0.05 μf ± 20% 400V		234,022
C32	Mylar	0.01 μf ± 20% 400V		234,021
C33	Met.Paper	0.1 μf ± 20% 200V		230,136
C34	Mylar	0.01 μf ± 20% 400V		234,021
C35	Mylar	0.05 μf ± 20% 400V		234,022
C36	Mylar	0.01 μf ± 20% 400V		234,021

		Description		BEC Part No.
C37	Met. Paper	0.1 µf ± 20% 200V		230,136
C38	Mylar	0.01 µf ± 20% 400V		234,021
C39	Mylar	0.05 µf ± 20% 400V		234,022
C40	Met.Mylar	0.047 µf ± 10% 400V	Goodall X663FR	236,002
C41	Met.Mylar	0.047 µf ± 10% 400V	Goodall X663FR	236,002
C42	(in "Bridge" unit)			
C43	(in "Bridge" unit)			
C44	Electrolytic	20 - 20 µf/450V	Mallory FP-234	283,100

NOTE:
Above voltage ratings are working volts.

- RESISTORS -

		Description		BEC Part No.
R1	Comp.	220 K ± 10% 1/2W	AB Type EB	301,027
R2	Comp.	4.7 K ± 10% 1/2W	AB Type EB	301,017
R3	Comp.	27 K ± 5% 1 W	AB Type GB	302,135
R4	Comp.	470 Ω ± 10% 1/2W	AB Type EB	301,011
R5	Comp.	47 K ± 5% 1 W	AB Type GB	302,141
R6	Var.comp.linear	50 K ± 10% 2 W	AB Type J	311,125
R7 thru R16	(in "Bridge" unit)			
R17	Comp.	470 K ± 10% 1/2W	AB Type EB	301,029
R18	Var.comp.linear	10 K ± 10% 2 W	AB Type J	311,144
R19	Comp.	470 Ω ± 5% 1/2W	AB Type EB	301,079
R20	Comp.	10 K ± 5% 1/2W	AB Type EB	301,111
R21	Comp.	470 Ω ± 5% 1/2W	AB Type EB	301,079
R22	Comp.	2.2 K ± 5% 1/2W	AB Type EB	301,095
R23	Comp.	470 K ± 10% 1/2W	AB Type EB	301,029
R24	Comp.	10 K ± 5% 1/2W	AB Type EB	301,111
R25	Comp.	1 M ± 10% 1/2W	AB Type EB	301,031
R26	Comp.	1 M ± 10% 1/2W	AB Type EB	301,031

Collection Copy

		Description		BEC Part No.
R27	Comp.	470 Ω ± 5% 1/2W	AB Type EB	301,079
R28	Comp.	2.2 K ± 5% 1/2W	AB Type EB	301,095
R29	Comp.	10 K ± 5% 1/2W	AB Type EB	301,111
R30	Comp.	470 K ± 10% 1/2W	AB Type EB	301,029
R31	Comp.	62 K ± 5% 1/2W	AB Type EB	301,130
R32	(Not Used)			
R33	Comp.	1 M ± 20% 1 W	AB Type GB	302,128
R34	Wire Wound	7.5 K ± 10% 10 W		312,100
D1	Diode	1N58AS	Sylvania	530,021
F1	Fuse	0.5A (SLO-BLO)	Buss MDL -.5	545,504
L1	Choke, RF	2.5 mh 200 ma.		400,014
L2	Choke, RF	2.5 mh 200 ma.		400,014
L3	Choke, RF Iron core	55 μh 300 ma.		400,015
L4	Choke, RF Iron core	55 μh 300 ma.		400,015
L5	Choke, Power	7 hy 500 Ω 50 ma.	Stancor C-1707	440,001
L6	Choke, RF	Special		400,026
M1	Meter,	Special Scale 200 μa		554,151
S1	Switch, Toggle DPDT		AH & H 81027AZ	465,101
S2 thru S4	(in "Bridge" unit)			
S5	Switch, Toggle SPST		Carling 110-63	465,105
T1	Transformer, Osc.	Special		075,010
T2, T3	(in "Bridge" unit)			
T4	Transformer, IF	Special		410,014
T5	Transformer, IF	Special		410,015
T6	Transformer, IF	Special		410,016

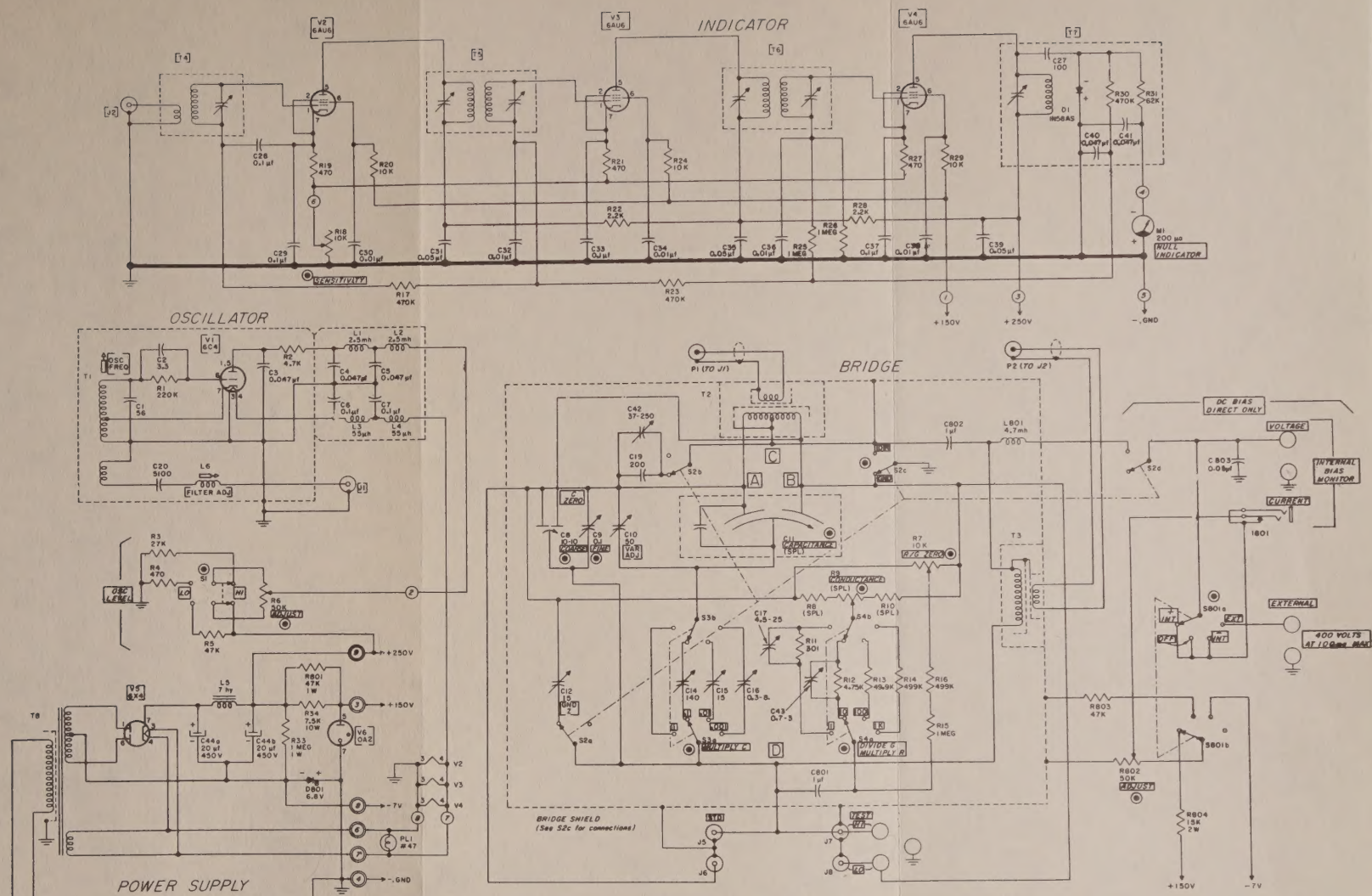
	Description			BEC Part No.
T7	Transformer, IF	Special Assembly		075,008
T8	Transformer, Power		Stancor PC-8401	446,007
V1	Tube	6C4		526,6C4
V2	Tube	6AU6		526,6AU6
V3	Tube	6AU6		526,6AU6
V4	Tube	6AU6		526,6AU6
V5	Tube	6X4		526,6X4
V6	Tube	OA2		526,OA2

SUPPLEMENTARY TABLE OF REPLACEABLE PARTS

FOR 75A-S8 CAPACITANCE BRIDGE AFTER

SERIAL NUMBER 328

Reference	Description			BEC Part No.
C801	Capacitor, Met.	0.5 μF 400V	Aerovox	230,118
C802	" Paper	0.5 μF 400V	Aerovox	230,118
C803	" Mylar	0.047μF 400V	Sprague	234,047
D801	Diode, Zener	6.8 V ±10% 3 W	Unitrode UZ806	530,041
J801	Jack, Phone		Switchcraft 13B	479,118
L801	Choke, R.F.	4.7 mH 95mA	Essex	400,102
R801	Resistor, Comp.	47K Ω ±10% 1 W	AB Type GB	302,023
R802	Resistor, Variable	50K Ω ±10% Log Taper	AB Type J	311,129
R803	Resistor, Comp.	47K Ω ±10% 1/2W	AB Type EB	301,023
R804	Resistor, Comp.	15K Ω ±5% 2 W	AB Type HB	304,115
S801	Switch, Rotary	2P4T Non-shorting	Oak Type J	466,171



SCHEMATIC DIAGRAM
(FOR SERIAL NUMBERS ABOVE 328)

CAPACITANCE BRIDGE
MODEL 75A-S8
(TEST FREQ: 1mc)

BOONTON ELECTRONICS CORPORATION

830,081-F

A.J. STAL DATE 3-58

NOTES
RESISTORS 1/2 WATT UNLESS NOTED
K-1,000
CAPACITANCE IN pf (µµf) UNLESS NOTED

PANEL GROUND
PANEL CONTROL
PIN NUMBER ON P3 and J3
PIN NUMBER ON P4 and J4
INTERNAL MARKING
EXTERNAL MARKING

EARLE & JONES INC.
NEW YORK
51020

MP MASTER
MA24773